Physics of Complex Systems

(1) Anderson (1972) "More is different"
→ "emergence"

(2) Goldenfeld & Kadanoff (1999)
"Simple Lessons from complexity" UNIVERSALITY
→ complex / chaotic behaviour ; no "model chaos" !

(1) Critique of "reductionist hypothesis"

"intensive" ⟵ "extensive"
(basic) research (applied) research

Reductionism ≠ Constructionism

Simple fundamental laws ⇏ Ability to reconstruct actual behaviour of the universe

2 problems
- scale → $N_A \sim 10^{23}$ → computer power → statistical mechanics
- complexity (emergence)

emergent behaviour (macroscopic) ≠ simple extrapolation from small systems

hierarchy of complexity levels
each level → NOVEL EMERGENT PROPERTIES

ELEMENTARY PARTICLES → SOLID STATE PHYSICS

→ EMERGENT PROPERTIES

PHASE TRANSITIONS (Thermodyn limit)

transition from a disordered "fully symmetric" phase

↓

to an ordered phase with a reduced symmetry → CRYSTALS (symmetry from elementary laws)

SPONTANEOUS SYMMETRY BREAKING

(2) Goldenfeld & Kadanoff

simple elementary laws → world / complex

complex → "structure with variation" / chaotic

- cells in different tissues
- turbulence

chaotic → sensitive dependence on initial conditions

complexity from very simple ingredients

- local interactions
- conservation laws (particle number, momentum)
- symmetry

} emergent turbulent behavior

INDEPENDENT OF DETAILS → "NO MODEL CHAOS"

→ UNIVERSALITY (independence on details at microscopic scale)

separation of length, time, energy scales

Example : Brownian Motion : / dissipative time scale
\ collision time scale

→ choose the relevant details in model description

③ NEWMAN (2011) "A Survey of Complex Systems"

- Networks
- Dynamical systems (chaos & bifurcation theory)
- Discrete dynamics (Cellular Automata) CA
- Scaling and criticality (power law behaviour)
- Adaptation (complex adaptive systems) & Game Theory
- Information Theory → (pattern) detection / communication (low information content)
- Computational complexity (polynomial vs. NP-complete problems)
- Agent-based models